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AN ANNOTATED BIBLIOGRAPHY ON HEAVY METAL TOLERANCE IN PLANT POPULATIONS

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Abouguendia, Z.M. and R.E. Redmann. 1979. Germination and early seeding growth of four conifers on acidic and alkaline substrates. For. Sci., 25:358-360*.

Germination and seedling growth of four conifers exposed to buffered extremes of pH was studied. The results are useful for species selection for revegetation of mine spoils, tailings and other sites with extreme pH.

Allen, R. and P.M. Sheppard. 1971. Copper tolerance in some California populations of the Monkey Flower, *Mimulus guttatus*. Proc. Roy. Soc. London, B., 177:177-196.

This study investigated the evolution of copper tolerance in *Mimulus guttatus* growing on abandoned copper mines. Populations growing on the normally toxic soil were tolerant to high levels of copper and also had some increased tolerance to zinc, lead and nickel even though these concentrations were not particularly high at that site.

Antonovics, J. 1966. The genetics and evolution of differences between closely adjacent plant populations with special reference to metal tolerance. Ph.D. Thesis, University of Wales, U.K.

Antonovics, J. 1968. Evolution in closely adjacent plant populations. V. Evolution of self-fertility. Heredity, 23:219-238.

Metal tolerant populations of *Agrostis tenuis* and *Anthoxanthum odoratum* have greater self-fertility than adjacent non-tolerant population of the same species. The degree of self-fertility is inherited and was interpreted as a barrier to gene flow.

Antonovics. J. 1972. Population dynamics of the grass *Anthoxanthum odoratum* on a zinc mine. J. Ecol., 60:351-365.

Individuals of *Anthoxanthum* were mapped over a 6-year period. Population density generally increased during summer months, but otherwise fluctuated erratically. Population turnover was rapid, therefore strong selection was acting to maintain the characteristics of the mine population. Population decay rate was considered to be influenced both by the environment and genotype.

Antonovics, J. and A.D. Bradshaw. 1970. Evolution in closely adjacent plant populations. VIII. Clinal patterns at a mine boundary. Heredity, 25:349-362.

This investigation showed that natural selection at a mine boundary is extremely complex and severe. Selection is multiple and independent for a wide variety of characters and plants must be adapted in numerous respects in order to survive.

Antonovics. J., A.D. Bradshaw and R.G. Turner. 1971. Heavy metal tolerance in plants. Adv. Ecol. Res., 7:1-85.

Plant and soil interactions involved in the ability of species normally non-tolerant, to evolve tolerant races were discussed. "Metal Tolerance" is specific to individuals of a species which are able to withstand greater concentrations of a heavy metal than their immediate relatives on normal soil.

Barry, S.A. and S.C. Clark. 1978. Problems of interpreting the relationship between the amounts of lead and zinc in plants *(Agrostis tenuis, Festuca ovina* and *Minuartio verna)* and soil on metalliferous (mining) wastes. New Phytol., 81:773-783.

The lead and zinc contents of shoot material of three plants and of the soil in which they were growing were determined. There were large differences between samples in the metal contents of the shoot material collected from soils having the same metal contents. Possible reasons for this variation included soil type, species and the degree of tolerance to the particular metal.

Berg, W.A. and W.G. Vogel. 1973. Toxicity of acid coal mine spoils to plants. p. 57-68 in: Ecology and Reclamation of Devastated Land, V. 1. R.J. Hutnik and G. Davis (eds.). Gordon and Breach, New York.

"Toxicity of extremely acid coal-mine spoil to plants is caused primarily by excess soluble Mn and Al. Mulching with hardwood chips raised the pH of the spoil, reduced soluble salts and lowered soluble Al.

Bradshaw, A.D. 1971. Plant evolution in extreme environments. p. 20-25 in: Ecological Genetics and Evolution. R. Creed (ed.). Blackwell Scientific Publications, Oxford, U.K.

A description of the characteristics and advantages of extreme environments in the study of evolution. Evolution on sea cliffs, mine tailings and ships' bottoms were used for examples.

Bradshaw, A.D. 1972. Some of the evolutionary consequences of being a plant. Evol. Biol., 5:25-47.

A discussion of the factors of evolution that are distinctive to plants. The author concluded that plants can evolve distinct populations on very small scales due to inherent phenotypic flexibility which enables them to cope with variations in the environment.

Bradshaw, A.D. 1976. Pollution and evolution. p. 135-195 in: Effects of Air Pollutants on Plants. T.A. Mansfield (ed.). Cambridge University Press, U.K.

There is widespread evidence of evolution in relation to pollution factors. The action and pattern of natural selection directly determines the outcome, by rapidly eliminating all those individuals except the most tolerant. Full tolerance can evolve in only one or two generations.

Bradshaw, A.D. 1977. The evolution of metal tolerance and its significance for vegetation establishment on metal contaminated sites. p. 599-622 in: Heavy Metals and the Environment. T.C. Hutchinson (ed.). Toronto University Press, Toronto, Canada.

This paper discusses the processes of evolution and natural selection occurring in metal tolerant populations. It appears that species populations that occupy toxic metal contaminated sites only do so because they have evolved tolerance. The populations that evolve tolerance appear to be restricted to those species that contain genes for tolerance.

Bradshaw, A.D. and M.J. Chadwick. 1980. The Restoration of Land. Blackwell Scientific Publications, Oxford, U.K., 331 p.

A discussion of special reclamation problems around the world. A good reference source.

Bradshaw, A.D., M.O. Humphreys and M.S. Johnson. 1978. The values of heavy metal tolerance in the revegetation of metalliferous mine wastes. p. 311-344 in: Environmental Management of Mineral Wastes. G.T. Goodman and M.J. Chadwick (eds.) Sijthoff and Noordhoff, Alphen aan den Rijn, Netherlands.

Vegetational establishment may counteract the adverse visual and environmental affects from heavy metal mining if toxicity, nutrient deficiency and physical checks on growth are overcome. The combined use of spoil amendments and metal-tolerant grass species are emphasized.

Bradshaw, A.D., T.S. McNeilly and P.P.G. Gregory. 1965. Industrialization, evolution and the development of heavy metal tolerance in plants. p. 327-343 in: Brit. Ecol. Soc. Symp. 5. G.T. Goodman et al. (eds.). Blackwell, Oxford, U.K.

Evolutionary changes have occurred in plant populations attempting to invade habitats made by man. *Agrostis tenuis* can be found growing on areas with quantities of lead, zinc, nickel or copper which would normally be toxic. A population tolerant of one metal was not tolerant of another unless the second was also present in the tolerant populations original habitat. There was no significant difference in the amount of toxic metal taken up by tolerant as opposed to non-tolerant plants. Populations successful in mine habitats were not successful in normal habitats.

Brown, R.W. and R.S. Johnston. 1978. Rehabilitation of a high elevation mine disturbance. p. 116-130 in: Proceedings: High Altitude Revegetation Workshop No. 3. Information Series No. 28. Colorado State University, Fort Collins.

Native subalpine and alpine grasses can be successfully used to establish plant cover on high elevation severe disturbances. Treatments including lime, organic matter, fertilizer and a surface mulch were essential to alter conditions of the spoil sufficiently to support plant growth and development. The inaccessibility of these areas and collecting native seeds are major points of concern.

Butterfield, R.I. and P.T. Tueller. 1980. Revegetation potential of acid mine wastes in northeastern California. Reclama. Rev., 3:21-31.

Acidity and low nitrogen availability in the spoil material were found to be the main limiting factors for successful revegetation of 14-year-old mine spoils. Transplanting was found to be an effective way of establishing tree and shrub seedlings.

Cook, S.C.A., C. Lefebore and T. McNeilly. 1972. Competition between tolerant and normal plant populations on normal soil. Evolution, 26:366-372.

The non-tolerant ecotype of three plant species tested had a greater dry weight than the zinc/lead tolerant ecotypes. This suggests that competition provides a selective pressure against tolerant ecotypes on uncontaminated soil thus promoting ecological isolation of two populations.

Coughtrey, P.G. and M.H. Martin. 1978. Tolerant of *Holcus lanatus* to lead, zinc and cadmium in factorial combination. New Phytol., 81:147-154.

The tolerance of *Holcus lanatus* to lead, zinc and cadmium alone and in combination was studied. A population of this species from a contaminated site showed tolerance to lead, zinc and cadmium in combination but another population revealed no tolerance to elevated metal levels.

Cox, R.M. 1976. Properties of some enzymes of zinc tolerant and non-tolerant clones of *Anthoxanthum odoratum*, Ph.D. Thesis, University of Liverpool, U.K.

Cox, R.M. 1979. Multiple tolerance relations in native plants and their application to reclamation. p. 202-205 in: International Conference Management and Control of Heavy Metals in the Environment. CEP Consultants LTD., Edinburgh, U.K.

The metal tolerance of various populations of the grass *Deschampsia cespitosa* and the birch *Betula papayrifera* were examined. The smelter clones were found to have significantly higher tolerances to all the metals except cadmium which was highly variable.

Cox, R.M. and T.C. Hutchinson. 1980. Multiple metal tolerance in the grass *Deschampsia cespitosa* (L) Beaur. from the Sudbury smelting area. New Phytol., 84:631-647.

The relevance of their findings to evolution of multi-metal tolerances and the possible uses of the species for reclamation are discussed. Various individuals in one population demonstrated a positive response to nickel and copper at high levels.

Cresswell, C.F. 1973. Changes in vegetation composition, nutritional status, soils, and microbial populations with the establishment of vegetation on gold-mine dumps on the Witwaterstrand. p. 335-359 in: Ecology and Reclamation of Devastated Land, V. 2. R.J. Hutnik and G. Davis (eds.) Gordon and Breach, New York.

Problems associated with establishing vegetation on gold-mine dumps in South Africa were discussed. The inorganic composition of the mine-dump soil, nutrient requirements of the vegetation, effects of pH changes and microbial population changes were considered.

Cyapowskyi, M.M. 1976. Annotated Bibliography on the Ecology and Reclamation of Drastically Disturbed Areas. U.S.D.A. Forest Service General Technical Report NE-21. U.S. Northeastern Forest Experiment Station, Upper Darby, Pa. 98 p.

Contains some valuable references.

Day, A.D. and K.L. Ludeke. 1973. Stabilizing copper mine tailing disposal berms with giant Bermudagrass. J. Environ. Qual., 2:314-315.

Experiments conducted in Arizona compared two methods, vegetative plugging and broadcast seeding, of establishing giant bermudagrass *(Cynodon dactylon* var. *ardius* Harlan et de Wet*)* on copper mine tailing berms. Plugging bermudagrass was more effective in stabilizing berms than broadcast seeding.

Day, A.D. and K.L. Ludeke. 1980. Direct seeding of tree species on copper, mine wastes in southwestern United States (Arizona). J. Environ. Qual., 9:304-306.

Experiments were conducted in Arizona to study the effects of four soil materials in copper mine wastes (desert soil, overburden, overburden plus tailings, and tailings) on germination, seedling establishment, and growth of five tree species. Planting of a variety of adapted trees on copper mine wastes in the southwestern U.S. is the most effective way to revegetate these disturbed areas and blend them into the surrounding environment.

Day, A.D. and K.L. Ludeke. 1980. Reclamation of copper mine wastes with shrubs in the southwestern U.S.A. J. Arid Environ., 3:107-112.

Experiments were conducted in Arizona to study seed germination, seedling establishment and growth of five species of shrubs in four soil materials associated with copper mining wastes. There was a progressive reduction in seed germination, seedling establishment, plant growth and ground cover from the more productive desert soil through overburden, overburden plus tailings to tailings. Planting a variety of adapted shrubs is believed to be the most effective way to revegetate these disturbed areas.

Day, A.D., K.L. Ludeke and T.C. Tucker. 1977. Influence of soil materials in copper mine wastes on the growth and quality of barley grain. J. Environ. Qual., 6:179-181.

Barley produced more grain and taller plants when seeded in desert soils than when planted in overburden or mine tailings.

Dean, K.C., R. Havens, K.T. Harper and J.B. Rosenbaum. 1973. Vegetative stabilization of mill mineral wastes. p. 119-136 in: Ecology and Reclamation of Devastated Lands, V. 2. R.J. Hutnik and G. Davis (eds.). Gordon and Breach, New York.

The U.S. Bureau of Mines is investigating methods for stabilizing mineral industry wastes. Physical, chemical, vegetative and combination methods have been developed with emphasis on combined chemical-vegetative stabilization.

Dean, K.C., R. Havens and E.G. Valdez. 1971. USBM finds many routes to stabilizing mineral wastes. Mining Engin., 23:61-63.

Many physical, chemical and vegetational stabilization methods of mineral wastes are presented. Perhaps the most innovative development is a combination chemical-vegetative stabilization method.

Down, C.G. 1974. Problems in vegetating metal-toxic mining wastes. p. 395-408 in: Minerals and the Environment. M.J. Jones (ed.). Institution of Mining and Metallurgy, London, U.K.

Physical and chemical conditions, in conjunction with metal toxicity, that inhibit revegetation of metal-toxic mining wastes were discussed. An integration of revegetation and mining plans may help solve some of the problems associated with these adverse conditions.

Dykeman, W.R. and A.S. DeSousa. 1966. Natural mechanisms of copper tolerance in a copper swamp forest. Can. J. Bot., 44:871-878.

This study attempted to identify the mechanisms by which soils, with large amounts of copper, support luxurious plant growth. Two conclusions were drawn. Firstly that copper is being chelated by organic substances and thus less available to the plants and secondly that copper is being immobilized within the plant roots.

Ernst, W. 1976. Physiological and biochemical aspects of metal tolerance. p. 115-133 in: Effects of Air Pollutants on Plants. T.A. Mansfield (ed.). Cambridge University Press, Cambridge, U.K.

This paper attempts to interpret the physiological and biochemical processes which give rise to heavy metal tolerance. Perhaps metal tolerance is due to changes in a large number of physiological parameters which involve cellular activity.

Farmer, E.E., B.Z. Richardson and R.W. Brown. 1976. Revegetation of acid mine wastes in central Idaho. U.S.D.A. Forest Service Research Paper INT-178 Ogden, Utah. 17 p.

The results of 2 years of revegetation research are described. Coupled with liming and fertilization, topdressing of mining wastes with selected overburden materials appears to be a highly desirable revegetation practice. Reacidification is expected to be a problem.

Fitter, A.H. and A.D. Bradshaw. 1974. Responses of *Lolium perenne Agrostis tenuis* to phosphate and other nutritional factors in the reclamation of colliery shale. J. Appl. Ecol., 11:597-608.

In a factorial experiment for N, P, K and limestone on five colliery shales, P was found to be deficient in all cases, but a response to N

was only found on the less acid shales. The response to P was correlated with various chemical estimates of soil P status through multiple regression equations. The significance of the regression coefficients and the value of the equations in reclamation work were discussed.

Fitter, A.H. and A.D. Bradshaw. 1974. Root penetration of *Lolium perenne* on colliery shale in response to reclamation treatments. J. Appl. Ecol., 11:609-615.

Colliery shale is very liable to droughting in its surface layers, so good root growth is essential for successful reclamation. There may be a direct stimulation of root growth by the presence of nutrients at a particular depth, and deep incorporation of fertilizers is recommended.

Foy, C.D., R.L. Chaney and M.C. White. 1978. The physiology of metal toxicity in plants. Annu. Rev. Plant Physiol., 29:511-566.

Physiology of some metal toxicities in plants with emphasis on the mechanisms of differential tolerances among species and cultivars within the same species was studied. Results indicate that mechanisms of tolerance for a given metal involve different complex interactions and pathways in different species and varieties.

Foy, C.D., A.J. Oakes and J.W. Schwartz. 1979. Adaptation of some introduced *Eragrostis* species to calcareous soil and acid mine spoil. Commun. Soil Sci. Plant Anal., 10:953-968.

The objective of this study was to determine the tolerance of some introduced *Eragrostis* species to calcareous soil and acid mine spoil. Results suggest that superior strains of this species can be selected for adaptation of these conditions.

Gadgil, R.L. 1969. Tolerance of heavy metals and the reclamation of industrial waste. J. Appl. Ecol., 6:247-259.

The zinc or copper tolerance of populations of grasses from mine spoils and other areas was tested in solution and the results were compared with the growth of populations on copper or zinc slag tips. The mine-spoil plants were generally more tolerant of copper or zinc. Factors other than toxicity of a single heavy metal apparently limit plant growth.

Gartside, D.W. and T.S. McNeilly. 1974. Genetic studies in heavy metal tolerant plants. I. Genetics of zinc tolerance in *Anthoxanthum odoratum*. Heredity, 32:287-297.

The genetics of zinc tolerance in *Anthoxanthum odoratum* was examined using the pair cross and diallel analysis techniques. Genetic control of zinc tolerance was found to be dominant and directional and under a polygenic control system.

Gartside, D.W. and T.S. McNeilly. 1974. Genetic studies in heavy metal tolerant plants. II. Zinc tolerance in *Agrostis tenuis*. Heredity, 33:303-308.

The genetics of zinc tolerance in *Agrostis tenuis* was examined using the diallel technique. Evidence presented showed genetic control of zinc tolerance is dominant and directional with a high additive genetic variance.

Gartside, D.W. and T.S. McNeilly. 1974. The potential for evolution of heavy metal tolerance in plants. II. Copper tolerance in normal populations of different plant species. Heredity, 32:335-348.

The distribution of copper tolerance of plant species grown from seed collected from uncontaminated areas was investigated. Only two species, *Agrostis tenuis* and *Dactylis glomerata*, were capable of evolving full tolerance in one cycle of selection indicating they have the number of qualified genes for tolerance within their gene pools.

Gemmell, R.P. 1971. The ecological behavior of species/populations of grasses susceptible and tolerant to heavy metal toxicity. Ph.D. Thesis, University of Wales, U.K.

Gemmell, R.P. 1972. Use of waste materials for revegetation of chromate smelter waste. Nature (Lond.), 240:569-571.

The chief conclusions of this work are that waste can be revegetated by treatment with organic materials or ferrous sulphate residues.

Gemmell, R.P. 1976. The maintenance of grassland on smelter wastes in the Lower Swansea Valley. I. Blast furnace slag. J. Appl. Ecol., 13:285-294.

Large-scale revegetation trials on blast furnace slag in the Lower Swansea Valley were observed from 1965-1970. A mixed sward grew best in the long-term. Additions of sewage sludge, and to a lesser extent domestic refuse, improved initial establishment but had less effect in the long-term. Annual applications of fertilizer were essential to ensure long-term success of the swards.

Gemmell, R.P. and G.T. Goodman. 1978. Problems of grassland maintenance on metalliferous smelter wastes. p. 335-356 in: Environmental Management of Mineral Wastes. Goodman, G.T. and M.J. Chadwich (eds.). Sijthoff and Noordhoff, Alphen aan den Rijn, Netherlands.

Revegetation trials in the Lower Swansea Valley, Wales were undertaken. If only a temporary grass cover is required, commercial grass varieties and organic matter additions can maintain acceptable swards. If long-term grass cover is required, the metalliferous wastes must be planted to metal-tolerant swards.

Gemmell, R.P. and G.T. Goodman. 1980. The maintenance of grassland on smelter wastes in the Lower Swansea Valley, III. Zinc Smelter Wastes. J. Appl. Ecol., 17:461-468.

Growth comparisons were made between zinc-tolerance and non-tolerant grass species on zinc wastes with varying applications of organic materials and pulverized fuel ash. Zinc-tolerant varieties outyielded the non-tolerant grasses over the range of soil amendment treatments.

Goodman, G.T. and R.P. Gemmell. 1978. The maintenance of grassland on smelter wastes in the Lower Swansea Valley. II. Copper smelter waste. J. Appl. Ecol., 15:878-883.

Large-scale grassland trails, using applications of organic materials and pulverized fuel ash on copper smelter waste, were set up in the Lower Swansea Valley in 1965 and monitored until 1970. If fertilizer applications were not maintained, swards become chlorotic and yields decreased in the second year; this was attributed to heavy metal toxicity and deficiencies of major nutrients.

Goodman, G.T., C.E.R. Pitcairn and R.P. Gemmell. 1973. Ecological factors affecting growth on sites contaminated with heavy metals. p. 149-173 in: Ecology and Reclamation of Devastated Land, V. 2. R.J. Hutnik and G. Davis (eds.). Gordon and Breach, New York.

Vegetation trials were initiated on sites contaminated with heavy metals and in the greenhouse. Factors which commonly prevented or retarded germination, establishment or plant growth were: "sand-blasting"; diurnal temperature extremes; water stresses; low pH; metal toxicity; macro-nutrient deficiency; and vandalism. Heavy-metal tolerant strains required less soil treatment and were more productive and persistent than commercial (non-tolerant) grass varieties.

Gregory, R.P.G. and A.D. Bradshaw. 1965. Heavy metal tolerance in populations of *Agrostis tenuis* and other grasses. New Phytol., 64:131-143.

Agrostis tenuis has been found growing on a variety of different mine workings in soils containing metal levels assumed to be toxic to this species. These populations were tested for tolerance to high concentrations of copper, nickel, lead and zinc. In general, the mine populations showed tolerances to the particular metals present in high quantities in the soils of their original habitats. The tolerances appears to be genetically controlled but the physiological mechanism involved was not clear.

Hickey, D.A. and T.S. McNeilly. 1976. Competition between metal-tolerant and normal plant populations; a field experiment on normal soil. Evolution, 29:458-464.

Unable to obtain a copy.

Hogan, G.C., G.M. Courtin and W.E. Rauser. 1977. Copper tolerance in clones of *Agrostis gigantea* from a mine waste site. Can. J. Bot., 55:1043-1050.

Copper-tolerant clones were found growing where soil copper levels were high and soil pH was low. Soils with equally high copper levels but higher pH and therefore lower extractable-copper levels did not support copper-tolerant clones.

Hogan, G.D., G.M. Courtin and W.E. Rauser. 1977. The effects of soil factors on the distribution of *Agrostis gigantea* on a mine waste site. Can. J. Bot., 55:1038-1042.

Soils from vegetated areas were compared to soils from areas contaminated with heavy metals. The soils from vegetated areas had higher pHs and lower water-extractable metals than soils from non-vegetated areas but failed to differ for any other factor measured.

Hogan, G.D. and W.E. Rauser. 1979. Tolerance and toxicity of cobalt, copper, nickel and zinc in clones of *Agrostis gigantea* (from a mine waste site). New Phytol., 83:664-670.

Three clones of *Agrostis gigantea* were evaluated for their tolerance to cobalt, copper, nickel and zinc. Copper was mot toxic to *A. gigantea*, followed by nickel, cobalt and zinc.

Hoiland, K. and P. Oftedal. 1980. Lead-tolerance in *Deschampsia flexuosa* from a naturally lead polluted area in S. Norway. Oikos, 34:167-172.

Studies of clones of *Deschampsia flexuosa* from polluted and non-polluted soils indicated that the plants naturally occurring in a root media containing higher lead concentrations were tolerant of this element. Relatively small amounts of lead were found in leaves of any of the clones indicating a selective mechanism working in the roots of the clone.

Humphreys, M.O. and A.D. Bradshaw. 1977. Genetic potentials for solving problems of soil mineral stress: heavy metal toxicities. p. 95-105 in: Plant Adaptation to Mineral Stress in Problem Soils. Proceedings of a workshop, Beltsville, Maryland. M.J. Wright (ed.). Ithaca, New York.

The characteristics of metal-tolerant plant material produced by artificial selection and natural selection are compared and discussed. A seed screening technique using mine soil with small amounts of potting compost has identified three metal-tolerant grass cultivars for use in reclamation.

Humphries, R.N. and A.D. Bradshaw. 1977. The establishment of woody plants on derelict land. Sci. Hortic., 29:23-33.

Woody plant species can be established successfully on most types of derelict land with proper site evaluation. In general, species likely to survive and perform well will be those tolerant of low fertility and extremes of pH and wetness.

Hunter, G.O. and P.C. Whiteman. 1974. Problems associated with the revegetation of metal-mining wastes. J. Aust. Inst. Agric. Sci., 40:270-278.

The objective of this paper was to evaluate problems associated with revegetation of metal-mining wastes. Revegetation is greatly influenced by nutritional deficiencies and microelement toxicities. Physical factors such as sand blasting are also a problem.

Hunter, G.O. and P.C. Whiteman. 1975. Revegetation of mine wastes at Mt. Isa, Queensland. 2. Amendment of nutrient status and physical properties of tailings for plant growth. Aust. J. Exp. Agric. Anim. Husb., 15:803-811.

Pot and field trials examined methods to overcome chemical and physical limitations of metal mine tailings to plant growth. Responses to additions of phosphorous, nitrogen and fly ash from coal fired power plants were recorded.

Hutchinson, T.C. and A. Kuja. 1979. Selection and use of multiple-metal tolerant native grasses for revegetation of mine tailings. p. 191-201 in: Management and Control of Heavy Metals in the Environment. Proceedings of the International Conference, London, U.K.

Many mine tailings sites in Canada are of extreme acidity, contain high concentrations of toxic heavy metals and are nutrient deficient and drought prone. Acid-tolerant and multi-metal tolerant native grass species have been selected and developed for low cost, long-term revegetation of these sites.

Hutchinson, T.C. and A. Kuja. 1979. The use of acid tolerant native grasses for reclamation of mine tailings. p. 1012-1016 in: Ecology and Coal Resource Development. M.K. Wali (ed.). Pergamon Press, New York.

Plant species already occupying metal contaminated areas were selected for screening on tailings in Canada. Results indicate that native species, if carefully selected and tested, can be used to revegetate even the most unfavorable tailings sites.

Hutnik, R.J. and G. Davis (eds.). 1973. Ecology and Reclamation of Devastated Land. Vols. 1, 538 p. and Vol. 2, 504 p. Gordon and Breach, New York.

The two volumes are comprised of proceedings from a symposium on Ecology and Reclamation of Drastically Disturbed Lands held in Pennsylvania in 1969. Volume 1 includes topics on chemical, physical and biological properties and their plants. Volume 2 includes such topics as species evaluation and reclamation techniques.

Jain, S,K. and A.D. Bradshaw. 1966. Evolutionary divergence among adjacent plant populations. I. The evidence and its theoretical analysis. Heredity, 21:407-441.

Studies have shown that steep clines, across mine boundaries can be maintained due to strong selective forces. This information along with ecological and genetic parameters were used to develop a model involving two environments with disruptive selection favoring different alleles.

Jeffery, D.W., M. Maybury and D. Levinge. 1974. Ecological approach to mining waste revegetation. p. 371-385 in: Minerals and the Environment. M.J. Jones (ed.). Institution of Mining and Metallurgy, London.

The two approaches generally used in revegetating metal mining wastes are burying waste material and using metal tolerant plant species. These approaches were combined and modified in revegetating wastes in Ireland and termed an ecological ameliorative approach. By considering the total ecology of the site, they hope to produce a stable maintenance-free plant cover.

Johnson, M.S. 1976. Plant growth on fluorspar mine tailings. J. Soil Water Conserv., 31:17-20.

Plant trials were established on tailings dumps to evaluate plant growth and species composition in response to added nutrients. Nitrogen and phosphorus must be added in order to establish and maintain vegetation.

Johnson, M.S. 1977. Establishment of vegetation on metalliferous fluorspar mine tailings. Ph.D. Thesis, University of Liverpool, U.K.

Johnson, M.S. and A.D. Bradshaw. 1978. Prevention of heavy metal pollution from mine wastes by vegetative stabilization. Trans. Inst. Min. Metall., 86:47-55.

Vegetative stabilization of metalliferous mine wastes is the most feasible alternative for preventing heavy metal pollution, however, it requires an understanding of the factors that affect plant growth in this inhospitable environment. Low nutrient status and lack of adequate nitrogen cycling are two of the many factors limiting plant growth.

Johnson, M.S., A.D. Bradshaw and J.F. Handley. 1976. Revegetation of metalliferous fluorspar mine tailings. Trans. Inst. Min. Metall., 85A:32-37.

Investigations show that the phytotoxicity of fluorspar tailings has decreased to a level at which commercial varieties of grasses and legumes may be used to establish a vegetation cover. The major limitations to plant growth are the very low levels of nitrogen and phosphorus in the wastes. A satisfactory vegetation cover can be established and can help to reduce the impact on the aesthetic and recreational values.

Johnson, M.S. and J.W. Eaton. 1980. Environmental contamination through residual trace metal dispersal from a derelict lead-zinc mine. J. Environ. Qual., 9:175-179.

Studies of historical and current environmental problems in the vicinity of a derelict Pb-Zn mine at Parc, in North Wales, have shown that heavy metal dispersal occurs through contaminated mine drainage waters and episodal erosion of an unstable tailings dam.

Johnson, M.S., T.S. McNeilly and P.D. Putwain. 1977. Revegetation of metalliferous mine spoil contaminated by lead and zinc. Environ. Pollut., 12:261-277.

This paper describes laboratory studies and field experiments for establishing plant growth on metalliferous mine spoil. Amendments of industrial wastes with appropriate combinations of species and fertilizers may be sufficient where revegetation is for recreation or amenity purposes.

Johnston, R.S., R.W. Brown, and J. Cravens. 1975. Acid mine rehabilitation problems at high altitudes. p. 66-79 in: Watershed Management Symp. Am. Soc. Civil Env., Utah State Univ., Logan.

Objectives of the project included the study and demonstration of surface mine rehabilitation techniques to achieve acid drainage abatement, revegetation, and improved visual impacts. Hydrologic analyses of flow patterns and quality are being emphasized. Related research activities include studies of plant species adaptability, revegetation techniques, and plant-soil-water relations for the alpine and subalpine mine disturbances.

Johnston, W.H. and G.T. Kelly. 1979. An abandoned mine, Bauloora, Cootamundra (Effect of heavy metal pollution of soil on plant growth, soil conservation). J. Soil Conserv. Serv. N.S.W., 35:179-183.

Greenhouse trials with polluted soil showed that plants failed to grow because toxic metal levels prevented root growth. The rehabilitation program involved applying 30 cm of topsoil, installing conservation earthworks and treating with lime and fertilizers.

Johnston, W.R. and J. Proctor. 1977. A comparative study of metal levels in plants from two contrasting lead-mine sites. Plant Soil, 46:251-257.

Metal levels in a number of plant species from two lead-mine spoil heaps were investigated. The results of plant and soil analyses for lead, zinc and calcium are presented along with a discussion of the influence of soil pH on the exchangeable lead and zinc concentrations.

Jowett, D. 1958. Populations of *Agrostis* sp. tolerant to heavy metals. Nature (Lond.), 182:816-817.

The method of testing metal tolerance in *Agrostis* spp. is described. General processes of toxicity and tolerance are discussed.

Karataglis, S.S. 1980. Differential tolerance of *Agrostis tenuis* populations growing at two mine soils to Cu, Zn, and Pb (copper, zinc, lead). Phyton, 20:15-22.

The tolerance of *Agrostis tenuis* Sibth. populations found in the area of two mines in England as well as in uncontaminated areas was studied. The populations proved tolerant to the particular metals present in high quantities in the soil of their original habitats.

Keane, P. and B. Craze. 1978. Captains Flat mined area field vegetation trials. J. Soil Conserv. Serv. N.S.W., 34:37-42.

Methods used and problems encountered in revegetating experimental embankments are described. Plant establishment was generally good but factors responsible for poor growth in certain sections were the presence of toxic material in the topsoil, overcompaction and moisture stress due to excess runoff.

Khan, M.S.I. 1969. The process of evolution of heavy metal tolerance in *Agrostis tenuis* and other grasses. M.Sc. Thesis, University of Wales, U.K.

Kuja, A.L. and T.C. Hutchinson. 1979. The use of native species in mine tailings revegetation. p. 207-221 in: Canadian Land Reclamation Association: Proceedings, fourth annual meeting. Guelph, Ontario, Canada.

Native species were selected from extreme acidic and metal contaminated sites and screened for their relative performance on tailings from Canada. Results show that native species could be an economic alternative to commercial species which are not acid or metal tolerant.

Lawrence, E.A. 1974. Summary of vegetation program on lead-zinc tailings. Am. Inst. Mining, Metallurgical and Petroleum Eng., Soc. Mining Eng. Trans., 256-306-307.

A multiple seeding and fertilization technique successfully revegetated lead-zinc tailings ponds in Canada. Legume establishment was much more difficult than for grasses.

Ludeke, K.L. 1973. Vegetative stabilization of copper mine tailing disposal berms of Pima Mining Company. p. 377-408 in: Tailings Disposal Today. C.L. Aplin and G.O. Argall (eds.). Miller Freeman Publications Inc., San Francisco.

The objectives of the project were to maintain the natural desert beauty, minimize wind and water erosion and establish a self-perpetuating plant community. The success of the vegetative stabilization has satisfied these objectives at a reasonable cost.

Lundberg, P.E., O.L. Bennett and E.L. Mathias. 1977. Tolerance of bermudagrass *Cynodon dactylon* selections to acidity. I. Effects of lime on plant growth and mine spoil material. Agron. J., 69:913-916.

The objective of this research was to study the growth of several bermudagrass selections on acidic strip mine spoil treated at various lime rates. Results indicate that toxicity of certain elements rather than low pH may limit bermudagrass production.

MacLauchlan, R.S. 1977. The search for "workhouse" plants that grow with little water or under water, plants that thrive in acid minespoil or sodic soil or salt, erosion. Soil Conserv., 42:5-9.

Eighteen plant material centers operated by the Soil Conservation Service continue to explore for and produce plants to help solve a variety of conservation problems.

Maclean, A.J. and A.J. Dekker. 1976. Lime requirement and availability of nutrients and toxic metals to plants grown in acid mine tailings. Can. J. Soil Sci., 56:27-36.

This paper discussed the lime requirement and some of the nutritional aspects in establishing vegetation in a number of acid pyrite-bearing tailings. The lime rates required to neutralize the acidity were impractically high however, with periodic leaching, the lime requirement for vegetation establishment can be reduced.

McCormick, L.H. and K.C. Steiner. 1978. Variation in aluminum tolerance among six genera of trees. For. Sci., 24:565-568.

Research was conducted to determine the relative tolerance of tree species to various levels of aluminum. Results indicate great differences among species in tolerance to aluminum however some species were tolerant to much higher aluminum concentrations than many agronomic crops and can be recommended for revegetating acidic mine spoils.

McNair, M.R. 1977. The genetics of copper tolerance in *Mimulus guttatus* (Scrophulariaceae), Ph.D. Thesis, University of Liverpool, U.K.

McNeilly, T.S. 1966. The evolution of copper tolerance in *Agrostis*. Ph.D. Thesis, University of Wales, U.K.

McNeilly, T.S. 1968. Evolution in closely adjacent plant populations. III. *Agrostis tenuis* on a small copper mine. Heredity, 23:99-108.

Copper tolerance of *Agrostis tenuis* in the vicinity of a small copper mine in North Wales subject to polarized wind direction was examined. Populations at the upwind end of the mine showed a sudden change in tolerant to non-tolerant individuals whereas populations sampled downwind remained tolerant for some distance. This indicated that gene flow follows the prevailing winds.

McNeilly, T.S. and A.D. Bradshaw. 1968. Evolutionary processes in populations of copper tolerant *Agrostis tenuis* Sibth. Evolution, 22:108-118.

Tests for copper tolerance on *Agrostis tenuis* populations from copper mines and nearby uncontaminated sites showed that populations growing on copper mines have copper tolerance whereas populations removed from contaminated sites by as little as 15.5 meters did not. Natural selection appears to be working for both populations, maintaining the status quo.

McNeilly, T.S. and M.S. Johnson. 1978. Mineral nutrition of copper-tolerant browntop on metal-contaminated mine spoil. J. Environ. Qual., 7:483-486.

The response of copper-tolerant *Agrostis tenuis* to a factorial set of macronutrient treatments (N, P, K, Ca) and harvesting was examined. Significant responses at two harvestings were obtained with Ca and N additions.

Miles, L.J. and G.R. Parker. 1979. Heavy metal interaction for *Andropogon scoparius* and *Rudbeckia hirta* grown on soil from urban and rural sites with heavy metals additions. J. Environ. Qual., 8:443-449.

A factorial experiment examined the growth of two plant species on two soils with all combinations of cadmium, zinc, lead and copper at two levels. The results failed to account for the stunting of growth noted on the urban site due to unquantified effects of soil pH and cation exchange capacity on metal uptake and transport.

Nicholls, M.K. and T.S. McNeilly. 1979. Sensitivity of rooting and tolerance to copper in *Agrostis tenius* Sibth. New Phytol., 83:653-664.

The rooting response of seven populations of *Agrostis tenuis* Sibth. to a range of copper concentrations is described. Variation in both index of tolerance and sensitivity of rooting to increased copper levels were found.

Nicklasson, A. and I. Soderberg. 1980. The flora around the (abandoned copper and zine) mine fields of Fredriksberg in southern Sweden. Sven. Bot. Tidskr., 74:19-24.

Heavy metal concentrations in the mine soil are sufficiently high to prevent most plants from colonizing the area however *Agrostis tenuis* and a limited number of other plants and mosses have occupied the site.

Nielson, R.F. and H.B. Peterson. 1972. Treatment of mine tailings to promote vegetative stabilization. Bulletin 485. Agric. Exp. Sta., Utah State Univ., Logan, 22 p.

This report describes some of the many laboratory, greenhouse and field investigations carried out to determine how to establish and maintain a vegetative cover on mine tailings. The prevention or correction of heavy metal toxicities was to incorporate lime. Nutrient deficiencies and wind erosion were corrected and controlled with commercial fertilizers and mulches respectively.

Nielson, R.F. and H.B. Peterson. 1973. Establishing vegetation on mine tailings waste p. 103-115 in: Ecology and Reclamation of Devastated Land, V. 2. R.J. Hutnik and G. Davis (eds). Gordon and Breach, New York.

Many plants were evaluated in the greenhouse for stabilizing tailings. The selected plants were well adapted to the adverse conditions found in tailings, with none significantly superior to others.

Palmer, M.E. 1978. Acidity and nutrient availability in colliery spoil. p. 85-126 in: Environmental Management of Mineral Wastes. G.T. Goodman and M.J. Chadwich (eds.). Sijthoff and Noordhoff, Alphen aan den Rijn, Netherlands.

Variability of spoil materials is a significant problem in reclamation and revegetation of colliery spoil heaps. Samples of spoils have pH values ranging from 8.0 down to 2.4. Extreme acidity is due to oxidation of iron pyrites and results in the precipitation of potassium.

Peters, T.H. 1970. Using vegetation to stabilize mine tailings. J. Soil Water Conserv., 25:65-66.

The procedure and practices for establishing vegetation on tailings in Ontario is described. Agricultural equipment was used for seeding, fertilizing and maintaining the revegetated areas.

Peterson, H.B. and R.F. Nielson. 1978. Heavy metals in relation to plant growth on mine and mill wastes. p. 297-309 in: Environmental Management of Mineral Wastes. G.T. Goodman and M.J. Chadwick (eds). Sijthoff and Noordhoff, Alphen aan den Rijn, Netherlands.

Wastes have been found to be highly variable in physical and chemical characteristics. The most successful plants are likely to be vigorous, non sensitive to nutrient deficiencies or nutrient imbalances and not especially attractive to grazing animals.

Peterson, P.J. 1969. The distribution of zinc-65 in *Agrostis tenuis* Sibth. and *A. Stolonifera L.* tissues. J. Exp. Bot., 20:863-875.

The distribution of Zinc-65 in zinc-tolerant and non-tolerant *Agrostis* spp. plants was investigated. Chemical fractionation of the roots revealed that zinc accumulated in the cell-wall fraction of the zinc-tolerant roots thus excluding toxic levels from the cytoplasm.

Peterson, O. 1976. Heavy metal ion uptake by plants from nutrient solutions with metal ion, plant species, growth period variations. Plant Soil, 45:445-460.

Results are presented from experiments of heavy metal uptake from nutrient solutions performed with different metals, concentrations and plant species. Cadmium uptake and translocation is emphasized.

Piccairn, C.E.R. 1969. An ecological study of the factors influencing vegetation of industrial waste heaps contaminated with heavy metals. Ph.D. Thesis, University of Wales, U.K.

Rascio, K. 1977. Metal accumulation by some plants growing on zinc-mine deposits. Oikos, 29:250-253.

Zinc accumulation in shoots, leaves and roots of three plants was investigated. Zinc accumulation was not equally distributed throughout the plants and zinc uptake varied throughout the growing season. It was postulated that different mechanisms for metal tolerance occur in different plant species.

Ratsch, H.C. 1974. Heavy-metal accumulation in soil and vegetation from smelter emissions. National Environmental Research Center, Ecological research series, EPA; 660/3-74-012, 23 p.

There has been a major impact on the soil and vegetation in the vicinity of a copper smelter in Tacoma, Washington. The accumulation of heavy metals in the soil have degraded some plant species and altered the composition of plant communities.

Shetron, S.G. and D.A. Carroll. 1977. Performance of trees and shrubs on metallic mine mill wastes. J. Soil Water Conserv., 32:222-225.

Investigations compared growth and survival of more than 30 tree and shrub species planted on stripping dumps, dikes and tailings basins at an iron and copper mine in Michigan's Upper Peninsula. Leguminous tree species performed best on these sites.

Simon, E. 1975. Vegetation dynamics in some metalliferous areas in the neighborhood of Eupen and Aachen in relation to edaphic factors. Bull. Soc. R. Bot. Belg., 108:273-286.

The soils from metalliferous places contained very high levels of lead and zinc which were toxic to plants. This powerful selective factor resulted in the occurrence of metallicolous taxa. Calcium acted as a strong moderator of the heavy metals toxicity. (Eng. Abs.)

Simon, E. 1977. Cadmium tolerance in populations of *Agrostis tenuis* and *Festuca ovina*. Nature (Lond.), 265:328-330.

The occurrence of cadmium tolerance in some Belgian and German populations of *Agrostis tenuis* and *Festuca Ovina* was investigated. Results showed that cadmium tolerance has a genetic basis and is a specific characteristic.

Simon, E. 1978. Heavy metals in soils, vegetation development and heavy metal tolerance in plant populations from metalliferous area. New Phytol., 81:175-188.

Heavy metal toxicity to plants in metal-contaminated areas depends on the metals mobility in soil and availability for plants in relation to the metal tolerance of the plant. Metal mobility in soil and availability to plants was investigated in both calcareous and non-calcareous situations.

Simon, E. and C. Lefebvre. 1977. Aspects of heavy metal tolerance in *Agrostis tenuis* Sibth., *Festuca ovina L.* and *America maritima* (Mill) Willd. Oecol. Plant., 12:95-110.

Heavy metal tolerance indices were studied in relation with plant species, metal concentration in the soil and other soil chemical characteristics. Plant populations occurring on heavy metal contaminated soils show heavy metal tolerance whereas populations on uncontaminated soil did not.

Smith, R.A.H. 1973. The reclamation of old metalliferous mine workings using tolerant plant populations. Ph.D. Thesis, University Liverpool, U.K.

Smith, R.A.H. and A.D. Bradshaw. 1970. Reclamation of toxic metalliferous wastes using tolerant populations of grass. Nature (Lond.), 227:376-377.

Field trials were established to compared reclamation techniques. Tolerant plant species were superior to non-tolerant commercial species and costs should approach those of establishing grassland on normal soils.

Smith, R.A.H. and A.D. Bradshaw. 1972. Stabilization of toxic mine wastes by the use of tolerant plant populations. Trans. Inst. Min. Metall., 81(A):230-237.

The use of tolerant plant populations and fertilizers is the most economically feasible reclamation technique if similar premine

vegetation is not required. Tolerant plant populations, with proper management, can last indefinitely compared to physico-chemical, techniques, which only last a short time.

Smith, R.A.H. and A.D. Bradshaw. 1979. The use of metal tolerant plant populations for the reclamation of metalliferous wastes. J. Appl. Ecol., 16:595-612.

Results suggest that high concentrations of toxic metals are the major cause of sparse vegetation cover but phosphorus concentrations are the immediate determinant. Naturally occurring tolerant populations grew faster and persisted longer on toxic spoils than normal commercial varieties.

Street, H.E. and G.T. Goodman. 1967. Revegetation techniques in the Lower Swansea Valley. p. 71-110 in: The Lower Swansea Valley Project. K.J. Hilton (ed.). Longmans, Green and Co., London, U.K.

The objective of the study was to develop techniques for an inexpensive establishment of vegetation on 800 acres of derelict land in Wales. Two main techniques were utlized. One of these was to use metal-tolerant grass clones and the second was to cover the old tips with at least nine inches of steel slag.

Turner, R.G. 1969. Heavy metal-tolerance in plants. Brit. Ecol. Soc. Symp., 9:399-410

This study of metal tolerance in plants indicates that toxic metals may either be excluded from the metabolic system or when present be prevented from exerting an effect because of changes in enzymes which allow normal processes to continue. The cell wall may act as a heavy metal accumulator.

Turner, R.G. 1970. The subcellular distribution of zinc and copper within the roots of metal tolerant clones of *Agrostis tenuis* Sibth. New Phytol., 69:725-731.

Experimental work attempted to localize a site of metal tolerance in roots of *Agrostis tenuis*. Large amounts of zinc and copper accumulated in the cell wall fraction of the metal-tolerant clones and this site may be involved in the heavy metal tolerance.

Turner, R.G. and R.P.G. Gregory. 1967. The use of radioisotopes to investigate heavy metal tolerances in plants. p. 493-509. in: Isotopes in Plant Nutrition and Physiology. IAEA/FAO, Vienna.

The study investigated the mechanism of zinc tolerance in a zinc-tolerant population of *Agrostis tenuis*. Evidence suggests that the cell wall/nuclear debris is the site of the mechanism of metal tolerance in *A. Tenuis* and that metal tolerance is achieved by regulation of metal ion entry into cellular metabolism.

Turner, R.G. and C. Marshall. 1971. The accumulation of Zn by root homogeneatis of Zn-tolerant and non-tolerant clones of *Agrostis tenuis*. New Phytol., 70:539-545.

Studies examined the distribution of zinc within root subcellular fractions in order to determine the potential of each fraction to accumulate zinc in excess of the normal physiological level. The cell wall fraction was the major site for zinc accumulation but when this fraction was removed other cellular components accumulated large amounts of zinc.

Turner, R.G. and C. Marshall. 1972. The accumulation of zinc by subcellular fractions of roots of *Agrostis tenuis* Sibth., in relation to zinc tolerance. New Phytol., 71:671-676.

This work examined zinc accumulation by subcellular root fractions in relation to the metal tolerance index of individual populations. Significant correlation was found indicating that the increased metal-binding capacity of the root is a major feature of the mechanism of heavy metal tolerance in *Agrostis tenuis*.

Tyler, G. 1976. Heavy metal pollution, phosphatase activity, and mineralization of organic phosphorus in forest soils. Soil Biol. Biochem., 8:327-332.

This study aimed to establish the influence of deposited heavy metals on fundamental processes of a spruce forest ecosystem in the vicinity of a brass mill. Decomposition rates, P minerlaization rates and phosphatase activity decrease with increasing degree of Cu and Zn pollution.

Urguhart, C. 1971. Genetics of lead tolerance in *Festuca ovina*. Heredity, 26:19-33.

Experimental investigations into the genetics of lead tolerance in *Festuca ovina* in an attempt to locate the mode of inheritance was described. Results show that lead tolerance in this species is an inherited characteristic probably controlled by a small number of genes.

Van Kakerix, L.K. and R.W. Brown. 1979. Seedling water relations of two grass species *(Poa alpine, Alopecurus pratensis* seedlings*)* on high-elevation acid mine spoils. USDA Forest Service research note INT. 252. United States-Intermountain Forest and Range Experiment Station. Ogden, Utah, 17 p.

Research was conducted at the McLaren Mine, near Cook City, Montana, to determine the effects of spoil-ameliorating treatments on water relations and growth of two grass species. Results indicate that the selected treatment should ameliorate spoil conditions within the physiological limitations of the plant species being used.

Vogel, W.G. and W.A. Berg. 1968. Grasses and legumes for cover on acid strip mine spoil. J. Soil Water Conserv., 23:89-91.

Of three perennial grasses which performed well in field trials, Weeping lovegrass consistently provided faster cover on more acid spoil. Usually, none of the grasses produced satisfactory cover

unless nitrogen fertilizer was applied. Two legumes grew and nodulated well when spoil pH's were greater than 4.5. Kobe *lespedeza* grew better than Korean *lespedeza* in spoils below pH 5.0.

Wainwright, S.J. and H.W. Woolhouse. 1975. Physiological Mechanisms of heavy metal tolerance in plants. p. 23-25 in: The Ecology of Resource Degradation and Renewal. M.J. Chadwick and G.T. Goodman (eds.). Fifteenth Symp. Brit. Ecol. Soc., Blackwell Scientific Publications, Oxford, U.K.

The mechanism of tolerance may involve a variety of physiological processes each of which contribute to the total metal tolerance. This is consistent with the fact that populations show various degrees of tolerance to a given metal.

Walley, K.A., M.S.I. Kahn and A.O. Bradshaw. 1974. The potential for evolution of heavy metal tolerance in plants. I. Copper and zinc tolerance in *Agrostia tenuis*. Heredity, 32:309-319.

A simple technique for screening populations for metal tolerance was performed by sowing seed samples in various mixtures of metalliferous waste and potting soil. Tolerant individuals were distinguished by their continuous growth whereas non-tolerant individuals died.

Weston, R.L., P.D. Gadgil, B.R. Salter and G.T. Goodman. 1965. Problems of revegetation in the lower Swansea Valley, an area of extensive industrial dereliction. Brit. Ecol. Soc. Symp. 5:297-325.

Evidence collected from greenhouse trials indicates that chemical factors such as macro-nutrient deficiency and heavy-metal toxicity inhibit plant growth in tip materials. Field evidence suggests that causes of failure on the tips may be more complex. Lack of suitable seed and such physical factors as unfavorable moisture and temperature regimes are also likely to hinder natural colonization. Treatments rendering tip material more suitable for plant growth may produce long-term effects beneficial to plant colonization.

Weston, S. 1973. Report on developments and progress in reclaiming waste dumps and tailings ponds. West. Miner, 46:29-37.

The author indicates that reclamation of tailings ponds is possible within economically practical limits. Special techniques, not normally associated with the agricultural approach, may be necessary and include such measures as aerial seeding and heavy fertilizer applications.

Wilkins, D.A. 1957. A technique for the measurement of lead tolerance in plants, Nature (Lond.), 180)37-38.

A method for the measurement of lead tolerance in *Festuca ovina* from soils of different lead contents is described.

Wilkins, D.A. 1978. The measurement to edaphic factors by means of root growth. New Phytol. 80:623-634.

The technique of measuring tolerance of plants to toxic ions, not originally designed for, is discussed and analyzed. The basic principle of measuring rates of root elongation in solutions with and without the toxic ion is still valid however many modifications and interactions must now be considered.

Williams, S.T., T.S. McNeilly and E.M.H. Wellington. 1977. The decomposition of vegetation growing on metal mine waste. Soil Biol. Biochem., 9:271-275.

The study compared several aspects of decomposition in metal mine waste colonized naturally by metal-tolerant *Agrostis tenuis* with those in an adjacent uncontaminated area. Evidence suggest that high concentrations of heavy metals in plant litter on metal mine waste inhibit the activity of decomposers.

Wu. L. and J. Antonovics. 1975. Zinc and copper uptake by *Agrostis stolonifera* tolerant to both zinc and copper. New Phytol., 75:231-237.

The results show that the mechanisms of copper and zinc uptake remain independent even while acting on the same individual. This confirms that copper and zinc binding sites responsible for metal tolerance are different.

Wu, L. and J. Antonovics. 1978. Zinc and copper tolerance of *Agrostis stolonifera* in tissue culture. Am. J. Bot., 65:268-271.

Research investigated metal tolerance of a clone of *Agrostis stolonifera* using a tissue culture technique. These results substantiate previous evidence that metal tolerance is genetically determined and acts at the cellular level. The tissue culture technique provides an alternative method of investigating metal tolerance in plants.

Wu, L. and A.D. Bradshaw. 1972. Aerial pollution and the rapid evolution of copper tolerance. Nature (Lond.), 238:167-169.

Copper tolerances of populations of *Agrostis stolonifera* from a contaminated area were compared with populations of the same species from an uncontaminated area. The results demonstrate a very rapid evolution in plants in relation to aerial pollution.

Wu, L., A.D. Bradshaw and D.A. Thurman. 1975. The potential for evolution of heavy metal tolerance in plants. Heredity, 34:165-187.

Grasslands of different ages which had been subjected to copper pollution for different lengths of time were used to follow the evolution of metal tolerance. Species diversity decreases with increasing pollution but there is an increase in the frequency of tolerant individuals as the age of the population increases. Populations have evolved by rapid selection of both seedling and adult stages in a single generation.

Wu, L., D.A. Thurman and A.D. Bradshaw. 1975. The uptake of copper and its effect on respiratory processes of roots of copper-tolerant and non-tolerant clones of *Agrostis stolonifera*. New Phytol., 75:225-229.

The greater capacity of roots of the tolerant clone to accumulate copper and thus inhibit transport of copper up to the leaves plays a role in the mechanism of copper tolerance. Oxygen uptake by roots of the tolerant clone were less sensitive to inhibition by copper than the non-tolerant clone.

Wyn-Jones, R.G., M. Sutcliffe and C. Marshall. 1971. Physiological and biochemical basis for heavy metal tolerance in clones of *Agrostis tenuis*. p. 575-581. in: Recent Advances in Plant Nutrition, V. 2. R.M. Smith (ed.). Gordon and Breach, New York.

The mechanism of zinc tolerance in clones of *Agrostis tenuis* was studied. Their results suggest that a specific zinc binding component exists in the cell walls of tolerant clones and that this contributes to tolerance.

* Abbreviations from Serial Sources for the Biosis Data Base. Bio Science Information Service. Philadelphia, PA.

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